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Article

Economic growth of India: The role of production, trade, and CO_2 emission based on the Granger causality

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Abstract: India's economic growth is of significant interest due to its expanding Gross Domestic Product (GDP) and global market influence. This study investigates the interplay between production, trade, carbon dioxide (CO_2) emissions, and economic growth in India using Granger causality analysis. Also, the data from 1994 to 2023 were analyzed to explore the relationships among these variables. The results reveal strong positive correlations among production, trade, CO_2 emissions, and GDP, with production showing significant associations with export, import, and GDP. Co-integration tests confirm the presence of a long-term relationship among the variables, suggesting their interconnectedness in shaping India's economic landscape. Regression analysis indicates that production, export, import, United States (US)-India trade, manufacturing cost of energy, and CO_2 emissions significantly impact GDP. Moreover, the Vector Error Correction Model (VECM) estimation reveals both short-term and long-term dynamics, highlighting the importance of understanding equilibrium and deviations in economic variables. Overall, this study contributes to a better understanding of the complex interactions driving India's economic growth and sustainability.

Keywords: CO_2 emission; production; export; import; economic growth; US-India trade

1. Introduction

Recently, India has emerged as a rapidly growing economy and has significantly impacted the global market, marked by a steady expansion in its Gross Domestic Product (GDP). Also, this economic growth, while promising, presents several challenges that necessitate a thorough understanding of its underlying factors (Das et al., 2017). GDP, a key metric reflecting the total market value of goods and services produced within a nation's borders annually, has surged from 6.5 to 7.2 in recent years, signifying a positive momentum in economic output (Biswas, 2023). Thus, the projections for the current quarter (Q2) 2023–2024 GDP indicate a further rise to 7.6%. Understanding the composition of this growth, particularly the role of manufacturing is vital for grasping its implications (Kartik, 2023). India's economic trajectory is closely intertwined with its global trade relationships, notably with the United States, where exports have experienced remarkable growth over the past decade. Meanwhile, the burgeoning trade ties underscore the need for a nuanced examination of their impact on India's economy (Yazawa, 2023). Additionally, India's vast potential for investment, especially in infrastructure, underscores the imperative to sustain its growth trajectory.

Despite these promising trends, challenges persist, including competition in international markets, as highlighted by the complexity's Indian exporters face

(Petropoulos et al., 2022). Moreover, India's export competitiveness has been uneven, as evidenced by historical inefficiencies in specific sectors like oilseed exports (Borisagar et al., 2023). Addressing these challenges requires a comprehensive understanding of the interplay between production, trade, CO_2 emissions, and economic growth. Recent studies have shed light on the intricate relationship between these variables, emphasizing the need for rigorous analysis to inform policy decisions (Paudel et al., 2024). The complex dynamics between economic growth and environmental sustainability, particularly about carbon emissions, necessitate a multifaceted approach (Marjanović et al., 2016). Empirical analyses, such as those employing the Autoregressive Distributed Lag (ARDL) model, have provided valuable insights into these relationships (Akalpler and Hove, 2019).

Building upon existing research, this study aims to deepen our understanding of the nexus between production, trade, CO_2 emissions, and economic growth in India. Additionally, the study seeks to uncover causal relationships and potential long-term implications for sustainable development by employing correlation and Granger causality models. Furthermore, this study addresses the gaps in previous research, particularly concerning the scarcity of studies utilizing causality models in this context and the challenges associated with data acquisition and analysis in the studied tourism, economy and CO_2 for the South Asian countries (Paudel et al., 2024). This study focuses on the production, trade, and CO_2 emission towards India's economic growth. The data were selected from Fred, and we aim to answer the research questions.

(1) Is there a bidirectional relation between Production, trade, and CO_2 emission towards the economic growth of India?

(2) What is the relationship between Production, trade, and CO_2 emission towards India's economic growth?

(3) Do these factors affect the country's sustainable development?

In addition to empirical analyses, theoretical frameworks such as Neo-Realism offer valuable insights into the evolving dynamics of India's trade relationships (Stein, 2015). Understanding the motivations behind increasing cooperation with trading partners, including potential security concerns, is essential for comprehensively assessing India's economic landscape. This study comprehensively analyses the intricate interplay between India's production, trade, CO_2 emissions, and economic growth. By integrating empirical findings with theoretical insights, we aim to offer valuable contributions to both academic scholarship and policy formulation in India's ongoing economic journey. Overall, the study's contribution includes understanding economic growth trends, the role of manufacturing in economic growth, global trade relationships, challenges and opportunities of the international market, environmental sustainability, and integration of empirical and theoretical insights. The remainder of this paper is organized as follows. The literature review and hypothesis are presented in section 2. Material and methods are given in section 3. Results and analysis are presented in section 4. Finally, the conclusion and policy implications are presented in section 5.

2. Literature review and hypothesis

2.1. Production and economic growth

The relationship between production and economic growth has been a subject of extensive study, reflecting the intricate interplay between various factors influencing a country's wealth over time. Namahoro et al. (2022) highlight the cross-sectional dependency between labour and capital, suggesting their integrated nature drives economic growth. Furthermore, Luqman et al. (2023) underscores the importance of understanding long-term co-integration relationships between production and economic growth, with implications for policy interventions to enhance the connection between labour, capital, and economic expansion. Similarly, by employing rigorous econometric methods, Kulshrestha and Agrawal (2019) study explored India's economy from 1961 to 2017, emphasizing production's crucial role in sustaining growth amid reforms and highlighting energy's positive impact on human development but also its adverse effects on overall economic growth, revealing intricate dynamics. Additionally, Batrancea (2021) mentioned the determinants of economic growth across various countries and periods, showing the pivotal role of bank capital, emissions, and credit in shaping growth trajectories. Likewise, Batrancea et al. (2021) studies encompass diverse regions such as Europe, Africa, and transition economies, offering valuable insights into the nuanced relationships between economic indicators and growth dynamics. Also, the impact of external shocks, such as the COVID-19 pandemic, on financial markets and economic growth was explored by Balcı et al. (2022), emphasized the need to understand non-market factors influencing price changes. Again, Islam et al. (2021) analysis of Saudi Arabia's economy underscores the importance of considering environmental variables alongside traditional economic indicators to understand growth patterns comprehensively. In the context of energy consumption, Wang et al. (2022) study on Pakistan reveals the complex relationship between different energy sources and economic output, advocating for a transition towards renewable energy for sustainable growth. In the same way, Batrancea et al. (2023) emphasize green policies and investments as crucial drivers for achieving sustainable economic growth across nations. Therefore, it is hypothesized that.

H1. Production has a causal relation with the GDP of India.

2.2. Trade and economic growth

The relationship between international trade and economic growth has been the subject of extensive research in economics. A study by Sreenu (2019) pointed out the co-integration between financial development, trade, and economic growth, highlighting the importance of macroeconomic stability in sustaining this relationship underscoring the significance of stable macroeconomic policies in ensuring favourable conditions for trade-led economic growth. Further, Kumari et al. (2023) examined the causal relationship between trade openness and economic growth, revealing no significant impact in either direction, with the changes in trade openness not substantially influencing economic growth, nor did economic growth significantly affect trade openness. In addition, Burange et al. (2019) explored the relationship between trade openness, investment, and economic growth in BRICS countries, finding stationary patterns in the variables and emphasizing the significant growth of the services sector in India, contributing notably to the country's economic advancement. Correspondingly, Batrancea et al. (2022) analyzed the impact of bank capital on economic growth in seven countries, highlighting the pivotal role of bank capital in driving economic growth across decades. Also, Batrancea (2021) explored the economic determinants of growth in different regions and contexts, such as Central and Eastern European countries, African nations, and the European Union. Studies highlighted the diverse factors influencing economic growth, from imports and exports to environmental considerations and financial indicators. Accordingly, it is hypothesized that.

H2a. Export has a causal relation with the GDP of India.

H2b. Import has a causal relation with the GDP of India.

H2c. US-India trade has a causal relation with the GDP of India.

2.3. Carbon emission and economic growth

The relationship between carbon emissions and economic growth has been a subject of considerable interest and research in recent years. In a study by Ahmad et al. (2016), carbon emissions, energy consumption, and economic growth were analyzed using advanced econometric techniques in India, which found a positive correlation between energy consumption and carbon emissions, contributing to understanding this relationship. Additionally, Bekun (2022) study used the Dynamic Ordinary Least Squares (DOLS) method to analyze the relationship between real GDP growth and non-renewable CO_2 emissions, finding a positive correlation. Granger causality analysis showed a one-way causal relationship, emphasizing renewable energy's role in emissions reduction and economic growth. Again, Hu et al. (2021) provided evidence suggesting that higher energy consumption significantly increases CO_2 emissions, and the finding underscores the need for sustainable energy policies to address environmental concerns while sustaining economic growth. Similarly, Batrancea et al. (2023) pointed to the sustainability of economic growth across 50 countries over 50 years. Nitrous oxide emissions significantly influence economic growth levels, highlighting the complex interplay between environmental factors and economic development. Further, Batrancea et al. (2021) study suggests increased investment and green policies to achieve sustainable economic growth. Also, Islam et al. (2021) focus specifically on Saudi Arabia, a nation heavily reliant on petroleum and natural gas reserves. It examines the impact of carbon emissions, rainfall, temperature, inflation, population, and unemployment on economic growth. Therefore, it is hypothesized that.

H3a. Manufacturing Energy Consumption (MEC) has a causal relation with the GDP of India.

H3b. CO_2 emission has a causal relation with the GDP of India.

Based on the existing literature that has extensively explored the intricate relationship between production, trade, carbon emission and economic growth, there remains a gap in understanding the nuanced mechanisms through which specific economic sectors (production, export, import, US-India trade, MEC, and CO_2 emission) contribute to overall growth dynamics in an Indian context.

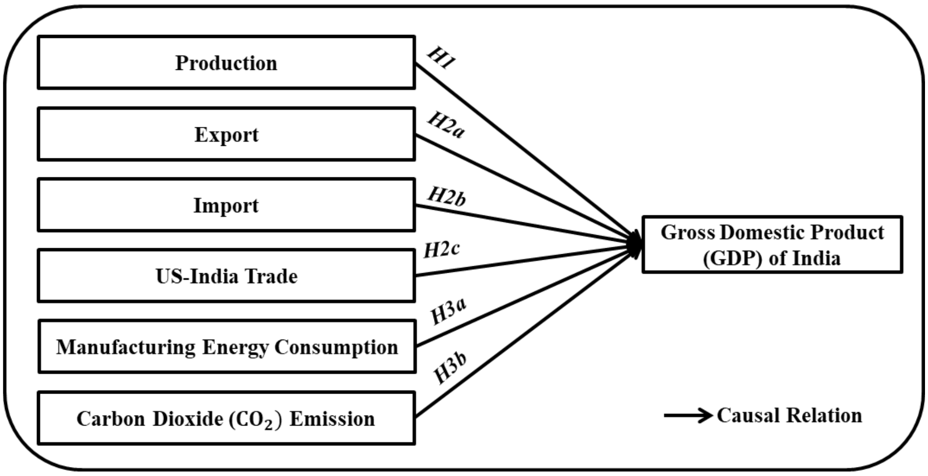

Figure 1. Conceptual framework.

Source: Figure by authors.

The conceptual framework is shown in **Figure 1** represents the causal relation between independent variables (production, export, import, US-India trade, manufacturing energy consumption (MEC), and carbon dioxide (CO_2) emission) and the dependent variable gross domestic product (GDP) of India.

3. Materials and methods

The current analysis assesses the impact and causality between drivers (production, export, import, US-India trade, MEC, and CO_2 emission) and GDP in India using a yearly dataset stretching from 1994 to 2023. The data are recorded based on the monthly frequency from April 1994 to September 2023. For instance, the production activities centred in the manufacturing sector require a high energy consumption rate due to production methods in the industry. The data are collected from the Fred/Microtrends (FRED, 2023) and OECD (OECD, 2023). Shahbaz and Rahman (2014) conducted a study investigating the relationship between GDP, exports, and financial development in Pakistan. Therefore, the current study used the restrictions testing method for co-integration and used the vector error correction model (VECM) and Granger causality test to analyze the data. Moreover, the results of the co-integration analysis confirmed the existence of a long-term relationship among the variables.

3.1. Data sources and measurement

The high production cost and limited availability of fullerenes have been significant obstacles in their development as practical materials for industries (Murayama et al., 2004). Also, increasing production in tons and ensuring a more abundant supply of fullerenes at a reasonable price is necessary, as per the study by (Mhonyera and Meyer, 2023), the unit of measurement used for the production in Tones. The trade deal is anticipated to create a net trade surplus, resulting in a positive impact on global trade, measured in US Dollars. The details of the measurement are mentioned in **Table 1**.

Table 1. Variables measurement units and sources.

Description	Measurement Unit	Sources
Production	Tonnes (Billions/Million)	Fred Economic Data/OECD
Export for India	USD Billion	Fred Economic Data/Macro trends
Import for India	USD Billion	Fred Economic Data/Macro trends
Manufacturing Energy	USD Billion	Fred Economic Data/OECD
US-India trade	USD Billion	Fred Economic Data/OECD
Carbon Emission	Tonnes (Billions)	Fred Economic Data/OECD
Economic Growth	USD Billion	Fred Economic Data/OECD/IMF

Source: Table by authors.

3.2. Regression equation

$$GDP = \beta_0 + \beta_1 \times production + \beta_2 \times export + \beta_3 \times import + \beta_4 \times US\ India\ trade + \beta_5 \times MEC + \beta_6 \times CO_2\ emission + \epsilon$$

GDP → Gross Domestic Product;

β_0 → intercept term;

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ → independent variables;

ϵ → error term.

Further, the study utilized various methods and results like descriptive statistics, correlation (Akoglu, 2018), unit root results (Salawu, 2017), Hausman test (Hausman, 1978), VIF (Marcoulides and Raykov, 2019), random, correlated random effect (Bell et al., 2019), heteroskedasticity test, the endogeneity test (O'Brien, 2017), Johansen's co-integration (Johansen, 1988), AR root test (Arltová and Fedorová, 2016), optimal lag selection (Bose et al., 2017), linear estimation (Schneider et al., 2010), VECM estimation (Liang and Schienle, 2019), granger causality (Granger, 1969), and bi-directional and unidirectional relation (Hernandez and Johnston, 2016).

4. Result and analysis

4.1. Descriptive statistics

Based on **Table 2**, the maximum ton of production is 129.1 billion tons, which could be the total manufacturing of India. The maximum carbon emission will be 2,648,780 by 2021.

Based on the above data, the maximum production tones are 129.1, which could be the total manufacturing of India. The maximum carbon emission will be 2,648,780 by 2021. In 2021, India's total exports amounted to $403 billion, positioning it as the 14th largest exporter globally. Also, the leading export categories for India include Refined Petroleum ($49 billion), Diamonds ($26.3 billion), Packaged Medicaments ($19.2 billion), Jewellery ($10.7 billion), and Rice ($10 billion). Additionally, the primary destinations for India's exports are the United States ($71.2 billion), United Arab Emirates ($25.4 billion), China ($23.1 billion), Bangladesh ($14.1 billion), and Hong Kong ($11.2 billion).

Table 2. Descriptive statistics.

	Production	Export	Import	US-IndiaTrade	MEC	CO_2	GDP
Mean	73.76238	1.58×10^{10}	2.34×10^{10}	2629.746	89.41147	1,583,392	1.50×10^{12}
Median	80.26529	1.47×10^{10}	2.27×10^{10}	2074.759	88.20350	1,494,632	1.28×10^{12}
Maximum	129.1691	4.21×10^{10}	6.47×10^{10}	8488.943	138.0200	2,648,780	3.42×10^{12}
Minimum	23.21451	1.90×10^{9}	1.90×10^{9}	360.1000	52.35900	685,903.0	3.27×10^{11}
Std. Dev.	32.63461	1.13×10^{10}	1.77×10^{10}	1927.347	21.89875	653,561.4	9.96×10^{11}
Skewness	–0.064367	0.269621	0.304718	0.829839	–0.083189	0.224965	0.435681
Kurtosis	1.488768	1.753702	1.850930	2.909197	2.414936	1.573377	1.860589
Jarque-Bera	33.93084	27.19960	24.95368	40.75095	5.457226	33.00594	30.34855
Probability	0.000000	0.000001	0.000004	0.000000	0.065310	0.000000	0.000000
Sum	26111.88	5.58×10^{12}	8.28×10^{12}	930929.9	31651.66	5.61×10^{8}	5.31×10^{14}
Sum Sq. Dev.	375951.3	4.51×10^{22}	1.10×10^{23}	1.31×10^{9}	169283.0	1.51×10^{14}	3.50×10^{26}
Observations	354	354	354	354	354	354	354

Source: Table by authors.

According to FRED (2023), India's total manufacturing production index was 100.7 in September 2023, a 0.4% increase from August 2023. Further, the total exports index for India was $34.5 billion in October 2023, a 0.6% increase from September 2023. The exports of goods and services for India were INR 10,98,000 crore in Q3 2023, a 2.4% increase from Q2 2023. Skewness is a measure of the asymmetry of the distribution of the series around its Mean.

The result in **Table 2** indicates that all the variables are positively skewed except for the production and manufacturing cost of energy. A normal distribution with a kurtosis value of 3 is called mesokurtic (Zhiqiang et al., 2008). Distributions with a kurtosis more significant than three are known as leptokurtic, while those with a kurtosis less than three are called platykurtic (Wuensch, 2005). The above results show that the kurtosis is less than 3. The data of the variables have a significant deviation from the normal distribution, and it can be assumed that the data are generally not distributed based on the *P* value from Jarque Bera (Ghasemi and Zahediasl, 2012).

4.2. Correlation

The correlation matrix in **Table 3** reveals strong positive associations among the variables, with all correlation coefficients being statistically significant, as indicated by *T* values exceeding the 1.9 threshold (Akoglu, 2018).

Production exhibits substantial positive correlations with export, import, and GDP. According to Forbes (2023), the manufacturing sector, a crucial production component, significantly contributes to India's GDP. Also, the Indian government's initiatives, such as production-linked incentive schemes, have benefited sectors like mobile phone and electronics manufacturing, fostering notable growth. However, it's crucial to acknowledge that India's global trade share remains relatively modest, prompting ongoing efforts to stimulate trade and attract foreign direct investment (FDI) (Paterson, 2019). The trade dynamics between India and the US reveal an asymmetry, with India relying more on the US for trade (Bao et al., 2023). This imbalance is attributed to the contrasting sizes of their economies, with the United

States exerting a more substantial influence on bilateral trade due to its larger economic strength (Cuñat and Zymek, 2022). Despite this, India actively pursues strategies to enhance trade and further bolster its economy.

Table 3. Correlation.

Probability	**Production**	**Export**	**Import**	**US-India Trade**	**MEC**	**CO_2**	**GDP**
Production	1						
Export	0.97566	1					
	83.47463						
	0.000						
Import	0.968965	0.995429	1				
	73.54209	195.5456					
	0.000	0.000					
US-India trade	0.970213	0.972017	0.966879	1			
	75.13954	77.63212	71.07261				
	0.000	0.000	0.000				
MCE	0.494012	0.579142	0.597231	0.546248	1		
	10.6601	13.32839	13.97017	12.23523			
	0.000	0.000	0.000	0.000			
CO_2	0.983201	0.972241	0.963774	0.979371	0.484992	1	
	101.0608	77.9586	67.79409	90.9322	10.40488		
	0.000	0.000	0.000	0.000	0.000		
GDP	0.985557	0.981514	0.975417	0.980388	0.492275	0.993955	1
	109.1896	96.21736	83.04561	93.33236	10.61062	169.8546	
	0.000	0.000	0.000	0.000	0.000	0.000	

Source: Table by authors.

4.3. Unit root test results

To determine whether the series in the data analysis are stationary (do not contain a unit root) or non-stationary (contain a unit root), several quantitative unit root tests were conducted (Salawu, 2017).

Table 4. Variable: Im, Pesaran and Shin W-stat.

	Level		**1st Level**	
	Intercept	**Intercept and Trend**	**Intercept**	**Intercept and Trend**
L (Production)	–0.565(0.874)	–5.644(0.000)	–12.519(0.000)	–12.500(0.000)
L (Export)	–1.343(0.610)	–1.629(0.779)	–17.197(0.000)	–17.216(0.000)
L (Import)	–1525(0.519)	–1.752(0.725)	–23.940(0.000)	–23.960(0.000)
L (US-India trade)	–0.990(0.757)	–2.821(0.190)	–6.220(0.000)	–6.238(0.000)
L(MEC)	–2.512(0.113)	–2.727(0.226)	–18.727(0.000)	–18.703(0.000)
L (CO_2)	–1.021(0.746)	–2.272(0.447)	–19.526(0.000)	–19.527(0.000)
L (GDP)	–0.871(0.796)	–1.525(0.819)	–4.018(0.000)	–4.061(0.000)

Table 5. Variable: Intermediate ADF test.

	Level		1st Level	
	Intercept (*P*-Value)	**Intercept and Trend (*P*-Value)**	**Intercept (*P*-Value)**	**Intercept and Trend (*P*-Value)**
Production	–0.565(0.875)	–12.519(0.000)	–5.644(0.000)	–12.508(0.000)
Export	1.343(0.610)	1.629(0.780)	17.197(0.000)	17.215(0.000)
Import	–1.525(0.520)	–1.752(0.726)	–23.940(0.000)	–23.960(0.000)
US-India trade	–1.424(0.570)	–2.327(0.417)	–6.275(0.000)	–6.355(0.000)
MEC	–2.512(0.113)	–2.727(0.226)	–18.726(0.000)	–18.702(0.000)
CO2	–1.021(0.746)	–2.272(0.448)	–19.525(0.000)	–19.527(0.000)
GDP	–0.871(0.797)	–1.525(0.819)	–4.018(0.000)	–4.060(0.000)

Source: Table by authors.

Table 6. Variable: Intermediate Phillips-Perron test.

	Level		1st Level	
	Intercept	**Intercept and Trend**	**Intercept**	**Intercept and Trend**
Production	–0.796(0.819)	–71.304(0.000)	–5.428(0.000)	–70.802(0.000)
Export	–1.262(0.648)	–2.021(0.587)	–27.024(0.000)	–27.024(0.000)
Import	–1.432(0.567)	–1.850(0.678)	–24.160(0.000)	–24.328(0.000)
US-India trade	–1491(0.536)	–7.734(0.000)	–58.984(0.000)	67.008(0.000)
MEC	–2554(0.104)	–2.811(0.194)	–18.726(0.000)	–18.702(0.000)
CO_2	–1.137(0.702)	–1.933(0.635)	–20384(0.000)	–20.481(0.000)
GDP	–0.848(0.803)	–1.339(0.876)	–20.399(0.000)	–20.406(0.000)

Source: Table by authors.

These tests include the Levin, Lin & Chu t-test (assuming a common unit root process) (Levin et al., 2002), Im, Pesaran and Shin W-stat (Im et al., 2003), Augmented Dickey-Fuller test (ADF) (Dickey & Fuller, 1979), and PP-Fisher Chi-square test (Baird, 1983). The results of these tests are presented in **Tables 4–6**. Several quantitative unit root tests were conducted to determine whether the series in the data analysis are stationary (do not contain a unit root) or non-stationary (contain a unit root). These tests include the Levin, Lin & Chu t-test (assuming a common unit root process), Im, Pesaran and Shin W-stat, Augmented Dickey-Fuller (ADF), and PP-Fisher Chi-square test. Before testing the unit root, all the variables are converted to a log. The results of these tests are presented in **Tables 4–6**.

4.4. Hausman test

A Hausman test (Hausman, 1978), which compares the two sets of estimates (fixed effects and random effects), rejects the alternate hypothesis of random effects in our model.

Table 7. Variance inflation factors.

Variable	Coefficient Variance	Uncentered VIF	Centred VIF
C	0.000866	17.79617	NA
Production	6.06×10^{-8}	8.099983	1.322834
Export	7.76×10^{-5}	875.4129	1.504676
Import	8.34×10^{-5}	752.1892	1.554448
US-India Trade	0.007571	469.8562	1.468345
MEC	1.35×10^{-7}	23.43757	1.322834
CO_2	0.000140	1387.590	1.307561

Source: Table by authors

Table 8. Cross section (fixed).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.61×10^{11}	1.59×10^{10}	−28.92942	0.0000
Production	1.68×10^{9}	3.73×10^{8}	4.513326	0.0000
Export	−3.582488	1.660596	−2.157351	0.0311
Import	2.134771	0.897192	2.379390	0.0174
US-India Trade	1.43×10^{8}	4479954.00	31.84942	0.0000
MEC	-2.42×10^{9}	1.33×10^{8}	−18.19313	0.0000
CO_2	1,063,299	20,902.77	50.86880	0.0000
		Effects Specification		
Cross-section fixed (dummy variables)				
R-squared	0.987000	Mean dependent var		1.50×10^{12}
Adjusted R-squared	0.986937	SD dependent var		9.95×10^{11}
SE of regression	1.14×10^{11}	Akaike info criterion		53.75645
Sum squared resid	3.19×10^{25}	Schwarz criterion		53.78696
Log-likelihood	–66,591.24	Hannan-Quinn criter.		53.76753
F-statistic	15,596.41	Durbin-Watson stat		0.349689
Prob(F-statistic)	0.000000			

Source: Table by authors

Table 9. Random effect.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.61×10^{11}	1.59×10^{10}	−28.92942	0.0000
Production	1.68×10^{9}	3.73×10^{8}	4.513326	0.0000
Export	–3.582488	1.660596	–2.157351	0.0311
Import	2.134771	0.897192	2.379390	0.0174
US–India Trade	1.43×10^{8}	4479954.	31.84942	0.0000
MEC	-2.42×10^{9}	1.33×10^{8}	−18.19313	0.0000
CO_2	1,063,299.00	20,902.77	50.86880	0.0000

Table 9. (*Continued*).

Effects Specification			
		SD.	Rho
Cross–section random		0.000000	0.0000
Idiosyncratic random		1.14×10^{11}	1.0000
Weighted Statistics			
R–squared	0.987000	Mean dependent var	1.50×10^{12}
Adjusted R-squared	0.986969	SD dependent var	9.95×10^{11}
SE of regression	1.14×10^{11}	Sum squared resid	3.19×10^{25}
F-statistic	31,268.75	Durbin-Watson stat	0.349689
Prob(F-statistic)	0.000000		
Unweighted Statistics			
R-squared	0.987000	Mean dependent var	1.50×10^{12}
Sum squared resid	3.19×10^{25}	Durbin-Watson stat	0.349689

Source: Table by authors.

Table 10. Correlated random effects.

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	0.000000	6	1.0000
* Cross-section test variance is invalid. Hausman statistic set to zero.			
** WARNING: The estimated cross-section random effects variance is zero.			

Source: Table by authors.

Table 11. Cross-section random effects test comparisons.

Variable	Fixed	Random	Var (Diff.)	Prob.
Production	1,682,144,384.183624	1,682,144,384.190386	3600.000000	0.9999
Export	–3.582488	–3.582488	0.000000	1.0000
Import	2.134771	2.134771	0.000000	1.0000
US-India Trade	142,683,930.464415	142,683,930.464460	0.078125	0.9999
MEC	–2,424,112,241.027436	–2,424,112,241.028520	186.000000	0.9999
CO_2	1,063,298.630779	1,063,298.630779	0.000065	1.0000

Source: Table by authors.

Table 12. Two-way random effects.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.46×10^{11}	2.46×10^{11}	1.405698	0.1599
Production	5.95×10^{8}	2.93×10^{9}	0.202996	0.8392
Export	–0.166882	12.03080	–0.013871	0.9889
Import	1.391708	6.565859	0.211961	0.8322
US-India Trade	1.33×10^{8}	33845012	3.937229	0.0001
MEC	-2.06×10^{9}	1.06×10^{9}	–1.952158	0.0510
CO_2	1104702.00	156637.6	7.052595	0.0000

Table 12. (*Continued*).

	Effects Specification			
			SD.	**Rho**
Cross-section random			0.001692	0.0000
Period random			1.15×10^{11}	1.0000
Idiosyncratic random			0.001143	0.0000
	Weighted Statistics			
R-squared	0.755830	Mean dependent var		0.010289
Adjusted R-squared	0.755237	SD dependent var		0.003736
SE of regression	0.003310	Sum squared resid		0.027071
F-statistic	1274.835	Durbin-Watson stat		0.005230
Prob(F-statistic)	0.000000			
	Unweighted Statistics			
R-squared	0.280221	Mean dependent var		1.50×10^{12}
Sum squared resid	1.76×10^{27}	Durbin-Watson stat		0.005571

Source: Table by authors.

Table 13. Heteroskedasticity Test: Breusch-Pagan-Godfrey.

F-statistic	28.15415	Prob. F (6,347)		0.0000
Obs*R-squared	115.9072	Prob. Chi-Square (6)		0.0000
Scaled explained SS	222.3832	Prob. Chi-Square (6)		0.0000
Variable	**Coefficient**	**Std. Error**	**t–Statistic**	**Prob.**
C	-3.31×10^{22}	7.89×10^{21}	–4.188837	0.0000
Production	-1.57×10^{21}	1.85×10^{20}	–8.529929	0.0000
Export	2.82×10^{12}	8.22×10^{11}	3.430822	0.0007
Import	-7.32×10^{11}	4.44×10^{11}	–1.647125	0.1004
US-India Trade	-1.42×10^{19}	2.22×10^{18}	–6.378512	0.0000
MEC	1.53×10^{20}	6.60×10^{19}	2.324011	0.0207
CO_2	9.99×10^{16}	1.04×10^{16}	9.648799	0.0000
R-squared	0.327422	Mean dependent var		1.29×10^{22}
Adjusted R-squared	0.315792	SD dependent var		2.57×10^{22}
SE of regression	2.13×10^{22}	Akaike info criterion		105.6816
Sum squared resid	1.57×10^{47}	Schwarz criterion		105.7582
Log-likelihood	–18698.65	Hannan-Quinn criter.		105.7121
F-statistic	28.15415	Durbin-Watson stat		0.848538
Prob(F-statistic)	0.000000			

Source: Table by author.

Table 14. Heteroskedasticity Test: White.

F-statistic	24.56523	Prob. F (27,326)	0.0000
Obs*R-squared	237.3433	Prob. Chi-Square (27)	0.0000
Scaled explained SS	455.3741	Prob. Chi-Square (27)	0.0000

Table 14. (*Continued*).

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-1.95×10^{23}	5.93×10^{22}	–3.288324	0.0011
Production^2	1.10×10^{19}	1.91×10^{19}	0.575020	0.5657
Production*Export	-9.50×10^{10}	1.10×10^{11}	–0.864624	0.3879
Production*Import	4.02×10^{10}	5.30×10^{10}	0.758719	0.4486
Production US-India trade	1.83×10^{18}	2.79×10^{17}	6.568183	0.0000
Production*MEC	2.87×10^{19}	1.26×10^{19}	2.283784	0.0230
Production*CO_2	-5.83×10^{15}	8.33×10^{14}	–7.004016	0.0000
Production	-1.06×10^{21}	2.17×10^{21}	–0.488081	0.6258
Export^2	–645.6521	285.3824	–2.262410	0.0243
Export*Import	516.7425	262.8211	1.966137	0.0501
Export*US-India trade	-1.80×10^{9}	1.23×10^{9}	–1.459653	0.1453
Export*MEC	-1.35×10^{11}	5.84×10^{10}	–2.312535	0.0214
Export*CO2	17650566	5191772.	3.399719	0.0008
Export	1.01×10^{13}	9.43×10^{12}	1.074188	0.2835
Import^2	–201.2472	89.98275	–2.236509	0.0260
Import*US-India trade	1.52×10^{9}	6.00×10^{8}	2.527705	0.0120
Import*MEC	4.90×10^{10}	3.25×10^{10}	1.508198	0.1325
Import*CO_2	–2324170.00	2985282.00	–0.778543	0.4368
Import	-8.47×10^{12}	5.34×10^{12}	–1.584796	0.1140
US-India trade ^2	-5.33×10^{15}	2.21×10^{15}	–2.414317	0.0163
US-India trade*MEC	6.97×10^{17}	2.07×10^{17}	3.371429	0.0008
US-India trade*CO_2	-6.94×10^{13}	1.58×10^{13}	–4.391815	0.0000
US-India trade	-7.56×10^{19}	2.80×10^{19}	–2.698008	0.0073
MEC^2	6.05×10^{18}	3.30×10^{18}	1.833732	0.0676
MEC*CO_2	-2.40×10^{15}	9.96×10^{14}	–2.408918	0.0166
MEC	-5.34×10^{20}	8.33×10^{20}	–0.641014	0.5220
CO_2^2	6.39×10^{10}	5.55×10^{10}	1.151981	0.2502
CO_2	5.02×10^{17}	1.62×10^{17}	3.100790	0.0021
R-squared	0.670461	Mean dependent var		1.29×10^{22}
Adjusted R-squared	0.643168	SD dependent var		2.57×10^{22}
SE of regression	1.54×10^{22}	Akaike info criterion		105.0869
Sum squared resid	7.70×10^{46}	Schwarz criterion		105.3929
Log-likelihood	–18572.38	Hannan-Quinn criter.		105.2086
F-statistic	24.56523	Durbin-Watson stat		1.244115
Prob(F-statistic)	0.000000			

Source: Table by authors

The tables above present statistical analysis results, likely from a regression model. **Table 7** shows variance inflation factors (VIF) for different variables, indicating values below 10, suggesting no significant multicollinearity issues (Marcoulides and Raykov, 2019). **Tables 8–12** present coefficients, standard errors, t-statistics, and other statistics for fixed effects, random effects, correlated random effects, and two-way random effects models (Bell et al., 2019). Heteroskedasticity tests are reported in **Tables 13** and **14**. These tables provide detailed insights into the model's coefficients, significance, and potential issues, such as multicollinearity and heteroskedasticity (O'Brien, 2017).

4.5. Co-integration test results

The next step involved conducting a co-integration test using Johansen's co-integration procedure (Johansen, 1988) to determine whether the variables were co-integrated. The reason for using Johansen's procedure is that it identifies the rank or number of co-integrating relationships, unlike the Engle-Granger Methodology, which assumes only one co-integrating equation regardless of the number of series (Camba Jr and Camba, 2021).

Table 15. Unrestricted Co-integration Rank Test (Trace).

Hypothesized		**Trace**	**0.05**	
No. of CE(s)	**Eigenvalue**	**Statistic**	**Critical Value**	**Prob.****
None *	0.505176	599.3895	125.6154	0.0001
At most 1 *	0.339963	376.3633	95.75366	0.0001
At most 2 *	0.281528	244.6627	69.81889	0.0000
At most 3 *	0.186002	139.8532	47.85613	0.0000
At most 4 *	0.127670	74.61556	29.79707	0.0000
At most 5 *	0.061606	31.31728	15.49471	0.0001
At most 6 *	0.034595	11.16073	3.841466	0.0008

Trace test indicates 7 cointegrating eqn(s) at the 0.05 level.
* Denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) *p*-values.
Source: Table by authors

Table 16. Unrestricted Co-integration rank test (Maximum Eigenvalue).

Hypothesized		**Max-Eigen**	**0.05**	
No. of CE(s)	**Eigenvalue**	**Statistic**	**Critical Value**	**Prob.****
None *	0.505176	223.0262	46.23142	0.0000
At most 1 *	0.339963	131.7006	40.07757	0.0000
At most 2 *	0.281528	104.8094	33.87687	0.0000
At most 3 *	0.186002	65.23765	27.58434	0.0000
At most 4 *	0.127670	43.29829	21.13162	0.0000
At most 5 *	0.061606	20.15655	14.26460	0.0052
At most 6 *	0.034595	11.16073	3.841466	0.0008

Max-eigenvalue test indicates 7 cointegrating eqn(s) at the 0.05 level.
* Denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) *p*-values.
Source: Table by authors.

The test results are presented in **Tables 15** and **16**. The results presented in the table demonstrate that the null hypothesis of no co-integration has been rejected. The trace statistic and maximum eigenvalue indicate the presence of one co-integrating equation at a significance level of 5%. For instance, in the case of the trace statistic, the value of 599.3895 significantly exceeds the critical value of 125.6154 at a 5% significance level. Furthermore, considering the significant p-value, we can confidently reject the null hypothesis of zero co-integration (Kao, 1999; Ssebulime and Edward, 2019). The table shows the results of the co-integration tests. Both tests reject the null of zero co-integrating vectors. There are seven co-integration equations, and it can be concluded that a co-integrating long-run relationship exists between the variables (Pedroni, 1999, 2004). This situation is similar to the finding of Hu et al. (2021) and Westerlund (2005).

4.6. AR Root test

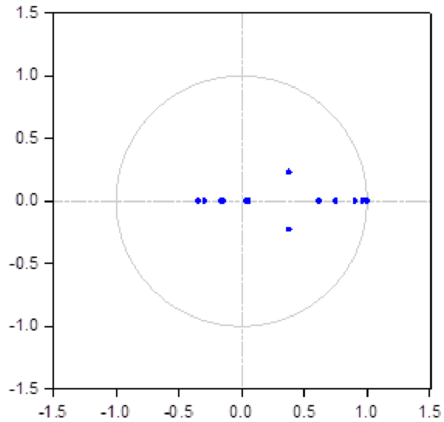

Figure 2. Inverse roots of AR characteristics polynomial.

Source: Figure by authors.

Based on the information provided in **Figure 2**, it can be observed that all characteristic roots fall within the range of a unit circle, indicating that the model is stationary (Arltová and Fedorová, 2016).

4.7. Optimal lag selection

The fundamental concept of Granger causality (GC) can be summarized as follows: if the prediction of one time series improves when incorporating information from a second time series, then the second time series is considered to have a causal influence on the first (Bose et al., 2017).

Table 17. Optimal lag selection.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−1738.748	NA	5.69×10^{-5}	10.09103	10.16884	10.12201
1	888.4450	5132.897	1.92×10^{-11}	–4.811821	**–4.189276***	**–4.563921***
2	958.4767	133.9912	1.70×10^{-11}	–4.933391	–3.766119	–4.468580
3	1024.731	124.0839	$\mathbf{1.54 \times 10^{-11}}$	**–5.033129***	–3.321131	–4.351405
4	1055.238	55.90011	1.72×10^{-11}	–4.926233	–2.669508	–4.027597
5	1109.518	97.26436	1.67×10^{-11}	–4.956752	–2.155300	–3.841204
6	1138.503	50.76619	1.88×10^{-11}	–4.841061	–1.494881	–3.508600
7	1182.758	75.71870	1.94×10^{-11}	–4.813630	–0.922724	–3.264257
8	1231.576	**81.55150***	1.96×10^{-11}	–4.812578	–0.376945	–3.046293

(*Optimal value) Source: Table by authors.

Table 17 of the lag selection criteria indicates that SC and HQ propose to lag one, while FPE and AIC proposed three lags. Based on the behaviours, lags give past values, and leads give future values. Lag length is important for the Granger causality to determine the bidirectional relationship between the variables. Further, regression analysis is a statistical technique utilized to examine the relationships between variables. It focuses on investigating the dependence of one variable on one or more other variables. When conducting regression analysis, our initial objective is to estimate the population regression function using the sample regression function as accurately as possible. In this case, the ordinary least squares (OLS) method was employed for estimation.

4.8. Linear Estimation with GDP

All the variables specified in **Table 18** below relate to GDP at 1% significance except for exports at 10% significance. To perform the linear estimation, it is essential to confirm that all the values are stationary.

Table 18. Linear estimation with GDP.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.290	0.682	10.690	0.000
Production	0.002	0.001	2.590	0.010
Export	0.074	0.043	1.736	0.083
Import	0.147	0.034	4.287	0.000
US- India trade	0.067	0.022	2.980	0.003
MEC	–0.001	0.000	–6.816	0.000
CO_2	1.045	0.054	19.267	0.000
R-squared	0.994	Mean dependent var		27.768
Adjusted R-squared	0.993	SD dependent var		0.774
SE of regression	0.063	Akaike info criterion		–2.680
Sum squared resid	1.366	Schwarz criterion		–2.604
Log-likelihood	481.415	Hannan-Quinn critter.		–2.650
F-statistic	8888.591	Durbin-Watson stat		0.266
Prob(F-statistic)	0.000			

Source: Table by authors.

According to Schneider et al. (2010), the model is good if the regression is close to 1. **Table 18** indicates that the R-Square is 0.994. This implies that about 99% of changes in GDP are explained by changes in independent variables. It could be considered that the model is a good fit. The Akaike info criterion (AICk) value is −2.680, and the log value is 481.415. AIC is minus two times the log-likelihood (Harju, 2016). The F-statistics 8888.591 (0.000) indicate that all the variables such as production, export, import, US-India trade, MEC, and CO_2 affect the dependent variables GDP.

4.9. VECM estimation: Length of co-integration

The vector error correction mechanism is estimated to understand the co-integration between the variables (Liang and Schienle, 2019). This estimation can analyze the long-term and short-term deviations from the equilibrium. **Table 19** below is derived from the estimated equation.

$$D(GDP) = C(43) + C(44) * production + C(45) * import + C(46) * export + C(47)*US\text{-}India\ trade + C(48)*MEC + C(49)*CO_2 + C(50)*GDP$$

Table 19. VECM short-run results.

Dependent variable D(GDP)	Coefficient	Std. Error	t-Statistic	Prob.
C (43)	–1.080544	0.376023	–2.873612	0.0043
C (44)	–0.000512	0.000311	–1.644761	0.1009
C (45)	–0.013006	0.016836	–0.772528	0.4403
C (46)	–0.004979	0.020625	–0.241416	0.8094
C (47)	–0.01371	0.010876	–1.260533	0.2083
C (48)	0.000191	0.000112	1.710084	0.0881
C (49)	–0.043334	0.037403	–1.158579	0.2474
C (50)	0.080886	0.025721	3.144759	0.0018

Source: Table by authors.

C (43) has negative significance, showing the variables' causality. The coefficient should be negative, demonstrating the ability to return to equilibrium. From C (44), a percentage increase in production can reduce the GDP by 0.0005. It has a minimal effect and no significance on the GDP. MEC signifies positive, indicating movement away from the equilibrium for the short term, which is significant at 10%. It can also be assumed that the increase in imports, US support to trade and carbon emission will reduce the GDP by 0.01% to 0.04%. It can be assumed that the independent variables do not affect the GDP in the short run but in the longer run. If the coefficient is negative, it indicates a long-run relation between the variables.

4.10. Granger causality test results

Granger causality is a statistical concept that leverages prediction to assess the strength of effective connectivity (Granger, 1969). Effective connectivity refers to one neural element's causal interactions or influences over another. Granger causality serves a dual role, encompassing both exploratory and confirmatory characteristics. In an exploratory sense, Granger causality identifies potential causal relationships by examining the predictive power of one time series on another (Beharelle and Small, 2016; Eggermont, 2023).

Table 20 shows results from a Granger causality analysis testing whether certain variables predict GDP. The analysis finds that Production, US-India trade, and CO2 emissions have a Granger causal relationship with GDP, as evidenced by their significant F-statistics, Chi-square values, and high R-squared values, indicating strong predictive power. In contrast, the hypotheses that Exports, Imports, and MEC predict GDP are not supported due to their higher p-values and insufficient statistical evidence. This suggests that only certain economic activities and environmental factors, like CO2 emissions, are significant predictors of GDP changes.

Table 20. Granger causality.

Null Hypothesis	F- Statistics	Chi-square	R-Squared	Decision
Production has a Granger Causal relation with GDP	11.9(0.000)	7.490 (0.057)	0.971	Supported
Export has Granger Causal relation with GDP	0.737(0.658)	3.785788(0.875)	0.963	Not Supported
Import has Granger Causal relation with GDP	0.997(0.437)	5.244484(0.731)	0.951	Not Supported
US- India trade has Granger Causal relation with GDP	9.410(0.000)	77.30608(0.000)	0.961	Supported
MEC have a Granger Causal relation with GDP	0.01402(1.000)	3.185027(0.922)	0.242	Not Supported
CO_2 has a Granger Causal relation with GDP	5.793(0.068)	2.522057(0.960)	0.987	Supported

Source: Table by authors.

4.11. Bi-directional and Unidirectional relation between the variables

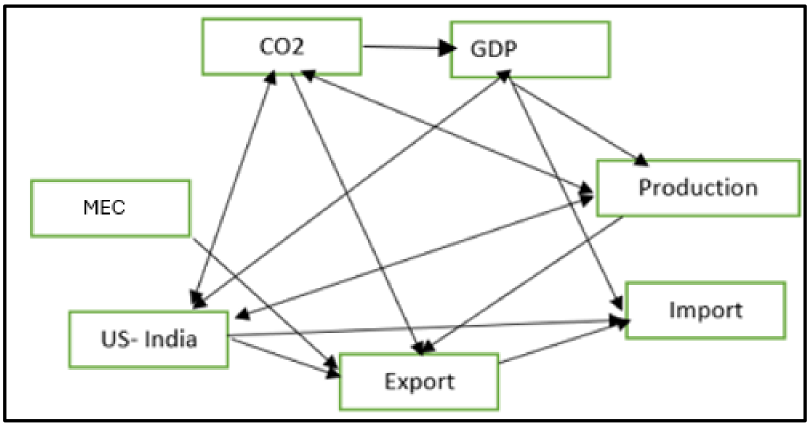

Figure 3. Bi-directional and Unidirectional relation between the variables.
Source: Figure by authors.

A unidirectional relationship means that data flow is just one way, and a bidirectional relationship means that the data flow is mutual between the related forms (Hernandez and Johnston, 2016). Based on the above **Figure 3**, CO_2 towards production and US-India has a bilateral relationship. In a bi-directional relationship, the influence flows both ways between two variables. It means that changes in one variable can affect the other and vice versa. Banerjee (2020) underscores the role of trade in CO_2 emissions, with the United Kingdom (UK) avoiding more emissions than India through their trade relationship. Production and US-India have a bilateral relationship. The economic relations between the US and India have seen significant growth, with a four-fold increase in trade and investment (Sahoo et al., 2012). Despite India's low per capita income and heavy reliance on agriculture, its production structure is comparable to that of the US (Gulati and Juneja, 2022).

5. Conclusion and policy implications

Based on the results, it is evident that the US-India trade has a causal relation with India's GDP. The US is now India's largest trade partner, with bilateral trade between the two countries accounting for 11.5% of India's total trade. According to

Iqbal et al. (2023), the economy will be significantly impacted when India maintains a trade surplus with the US and a deficit with the other trading partners. To develop effective strategies, it is crucial to evaluate the potential impact of the global pandemic on both total exports and imports of merchandise (Mena et al., 2022).

5.1. Conclusion

The statistical analysis reveals significant aspects of India's economic landscape, highlighting a maximum production capacity of 129.1 billion tons and corresponding carbon emissions of 2,648,780 tons by 2021. India's global trade position, with $403 billion in exports in 2021, emphasizes its status as the 14th largest exporter globally. Strong positive correlations among variables, especially with production, underscore the manufacturing sector's vital role in India's GDP. Co-integration tests confirm a long-term relationship among variables, while regression analysis indicates robust relationships with GDP. Granger causality testing adds a predictive dimension, exploring effective connectivity in the economic and environmental spheres. While neorealism focuses solely on systemic factors, neoclassical realism considers how India's domestic dynamics (such as state-society relations, political regime, and strategic culture) influence its trade policies. By examining the variables, neoclassical realism provides a more nuanced understanding of India's trade behaviour.

5.2. Policy implications

Sustainable manufacturing practices are crucial to balance economic growth with environmental concerns. Policymakers should consider strategies to enhance global trade partnerships, especially with essential export destinations, to further boost India's economic standing. Understanding the dynamic relationships between variables is crucial in formulating targeted and effective economic policies. It includes incentivizing sustainable practices in the manufacturing sector, fostering innovation, and addressing environmental challenges. The findings provide valuable insights for policymakers to make informed decisions, contributing to India's sustainable development goals and economic resilience. Critics argue that neoclassical realism is comparatively inefficient and faces challenges. Future research can concentrate on foreign policy theories and exploring the politics of international cooperation.

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